

# eRD17: BeAGLE

A Tool to Refine **Detector Requirements** for eA  
in the Saturation Regime

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23-January-2017

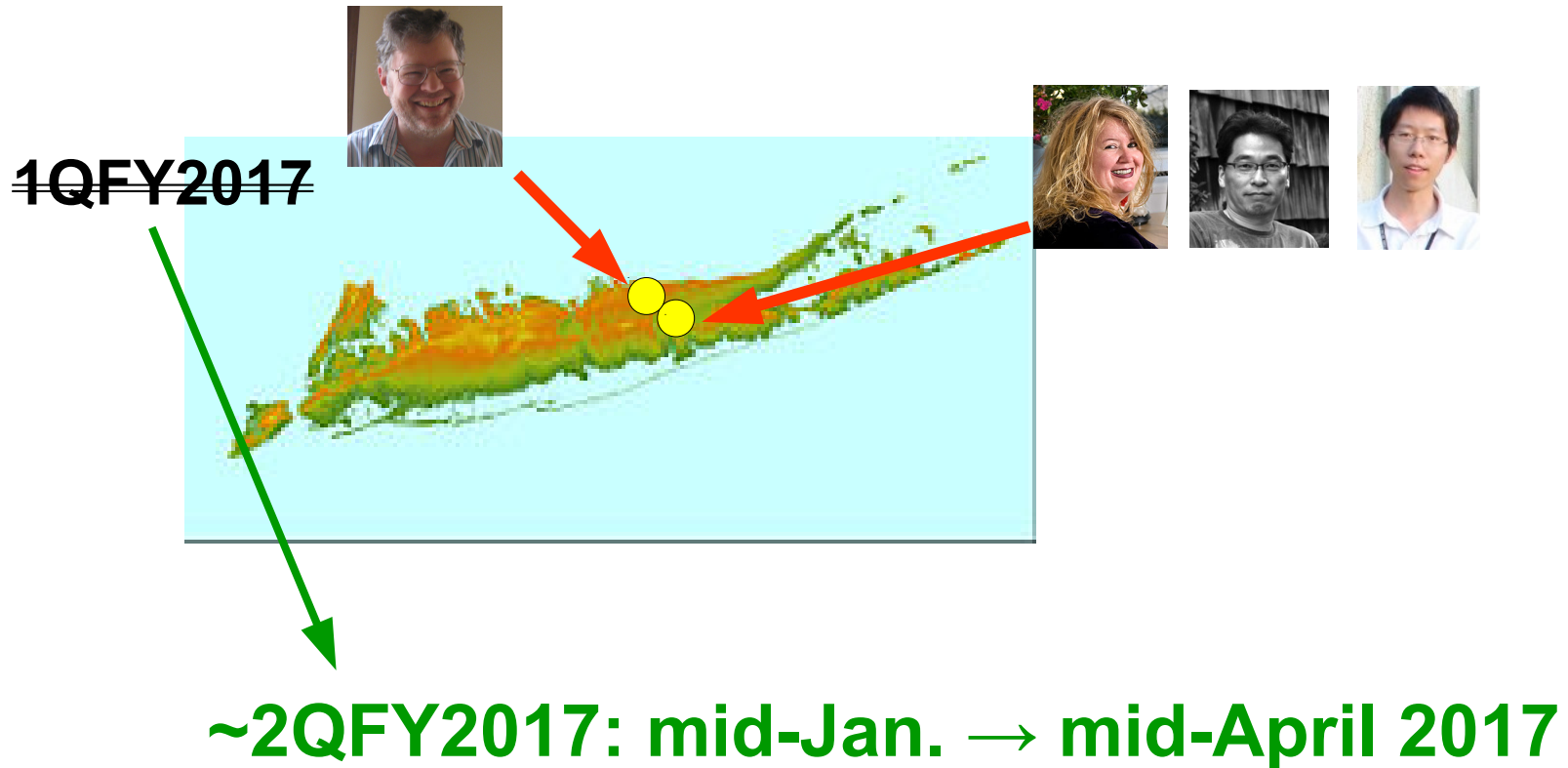
**\*-co-PIs**

# eRD17: BeAGLE

Benchmark **eA** Generator for **LE**ptoproduction



# Everyone's on Long Island now!

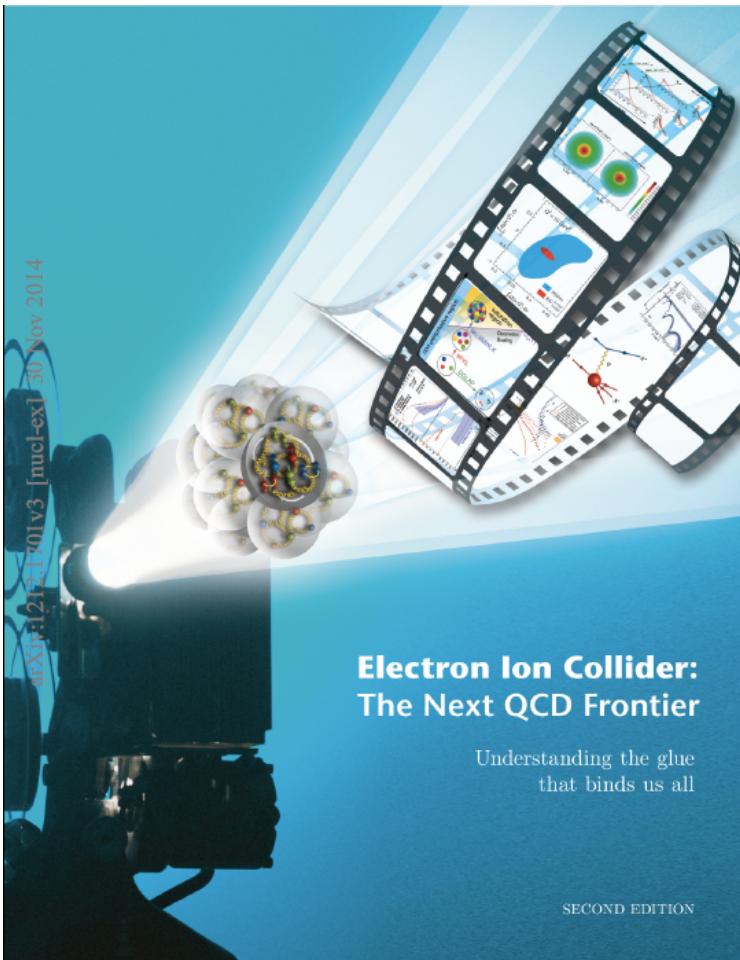


# Saturation at EIC is multi-nucleonic

## Executive Summary (page ix)

To date this saturated gluon density regime has not been clearly observed, but an EIC could enable detailed study of this remarkable aspect of matter.

This pursuit will be facilitated by electron collisions with heavy nuclei, where **coherent contributions from many nucleons** effectively amplify the gluon density being probed.



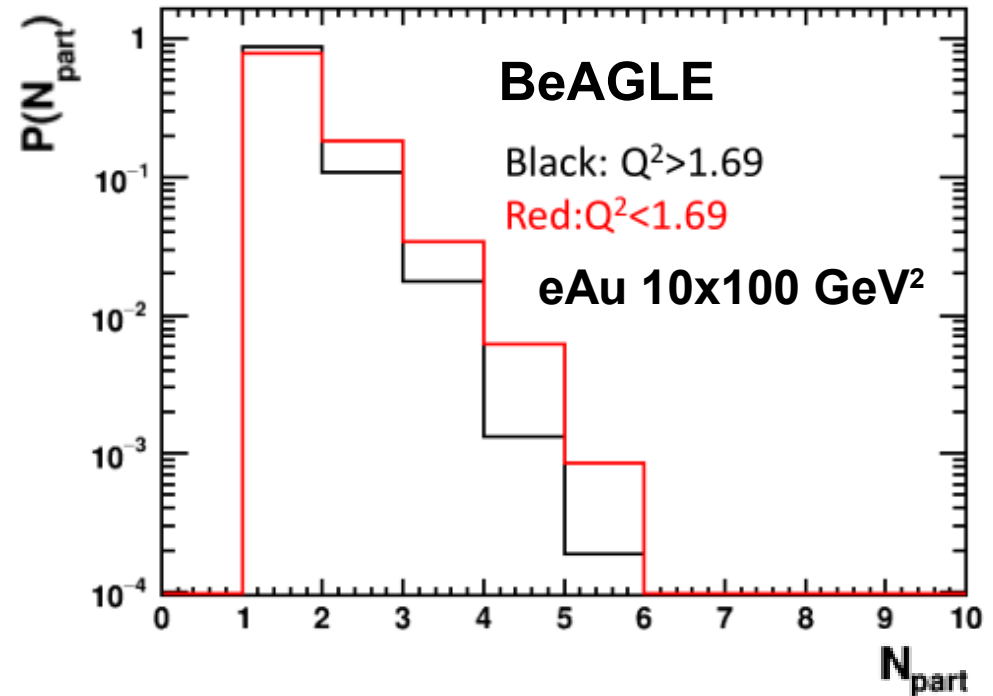
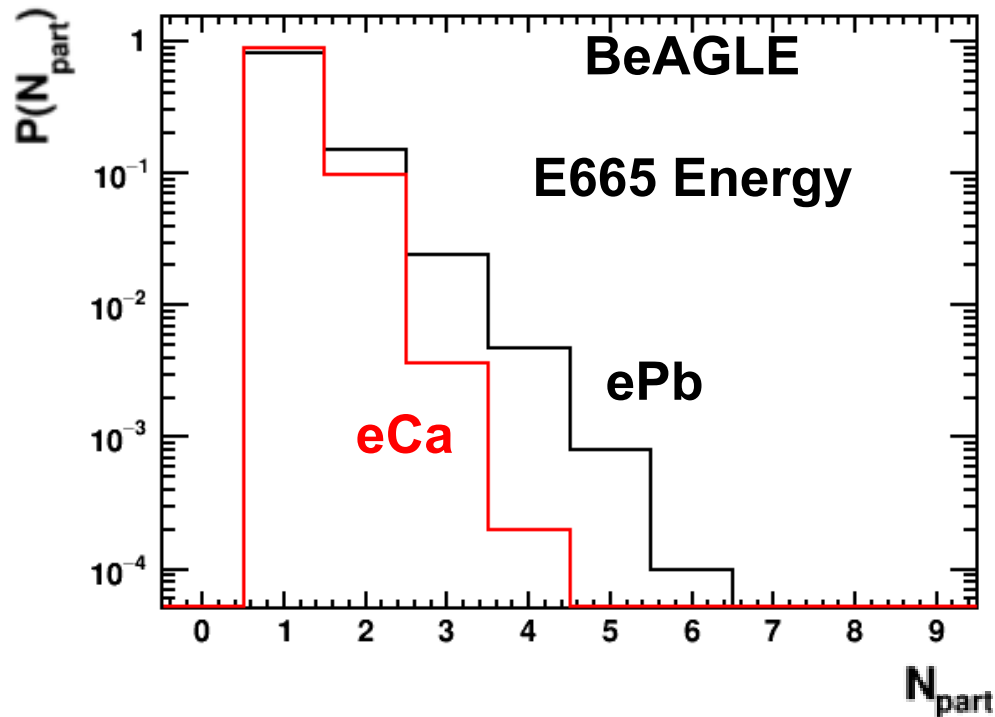
# eRD17 in a nutshell

- Forward detector/IR design is happening NOW
- DIS Models for eA have a serious deficiency.
  - Missing multinucleon DIS events (shadowing).
  - We don't really know how complete the forward coverage needs to be.
- Upgrade DPMJetHybrid to include known effects
- Simulate a couple of key measurements.
- Project duration: FY2016-FY2017

# State of eA(DIS) models pre-eRD17

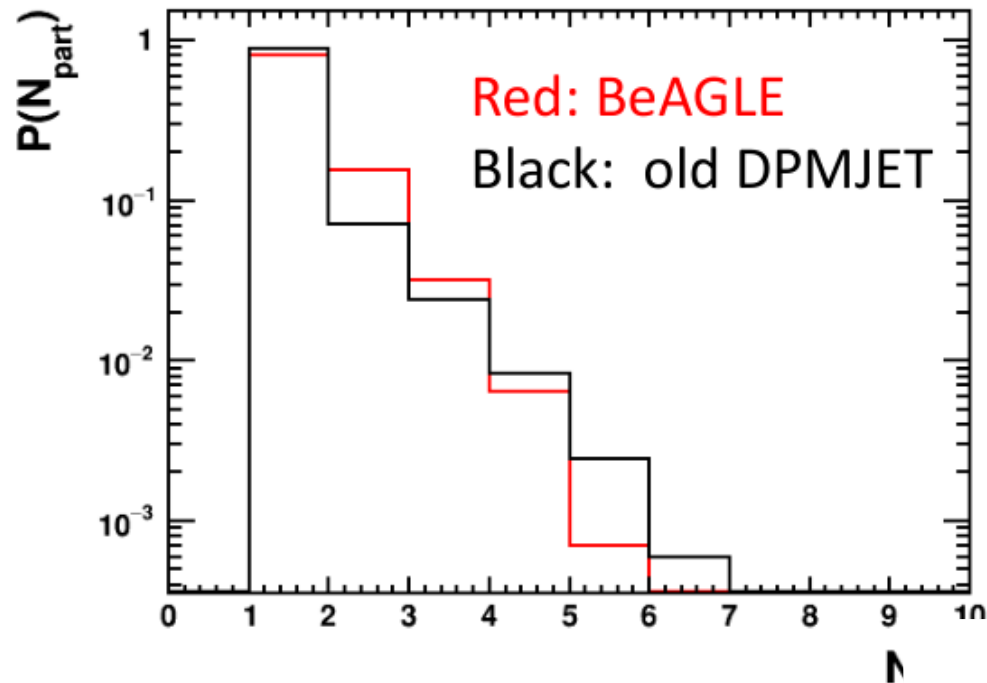
Features	DPMJet	Pythia (EIC)	DPMJet-Hybrid	BeAGLE (planned)
1. Hard processes correct.	NO	YES	YES	YES
2. Tuned to ZEUS $ep \rightarrow p+X$ data	NO	YES	YES	YES
3. IntraNuclear Cascade	YES	NO	YES	YES
4. Nuclear evaporation/breakup	YES	NO	YES	YES
5. Multinucleon shadowing available.	YES	NO	NO	YES
6. Correct nucleon remnant (n/p)	YES	NO	NO	YES
7. Tuned to E665 $\mu\text{Pb} \rightarrow n+X$ data	YES	N/A	YES	YES
8. Shadowing coherence length	YES	N/A	NO	YES

# Multinucleon shadowing w/ Pythia hard event!



$1 < Q^2 < 20 \text{ GeV}^2$ ,  $0.01 < y < 0.95$   
INC parameter:  $\tau_0 = 9 \text{ fm}$

# Multinucleon shadowing w/ Pythia hard event!



eAu 10x100 GeV<sup>2</sup>  
 $1 < Q^2 < 20$  GeV<sup>2</sup>,  $0.01 < y < 0.95$   
INC parameter:  $\tau_0 = 9$  fm

# BeAGLE – Benchmark eA Generator for LEptoproduction

# Rename of DPMJetHybrid

Developed at BNL  
Also running at JLAB

```
login.jlab.org - PuTTY
```

```
+-----+  
| Welcome to BeAGLE - Benchmark eA Generator for LEptoproduction |  
+-----+  
  
|          BBBB   EEEEE   A      GGGGGG LL      EEEEEEE |  
|         BB B EE       A A    GG     LL      EE        |  
|         BB B EE       A A    GG     LL      EE        |  
|         BBBB   EEEEE   AAAA   GG  GG  LL      EEEEE   |  
|         BB B EE       A      A GG  G  LL      EE        |  
|         BB B EE       A      A GG  G  LL      EE        |  
|         BBBB   EEEEEEE A      A GGGGGG LLLLLL EEEEEEE |  
+-----+  
  
| Pre-release version |  
+-----+  
  
| Authors: Elke Aschenauer, Mark D. Baker, J.H. Lee, Liang Zheng |  
| Contact: liangzhphy@gmail.com or mdbaker@mdbpads.com           |  
+-----+  
  
| This program (previously called DPMJethybrid) links to:  
| DPMJET, PHOJET, & PYTHIA (see version #s below) including also  
| LHAPDF for pdfs, and FLUKA & PyQM for conventional nuclear effects  
+-----+
```

```
jlab13.jlab.org>
```

# eRD17 Progress

Features	DPMJet	Pythia (EIC)	DPMJet-Hybrid	BeAGLE $\beta$ (NOW)	BeAGLE (planned)
1. Hard processes correct.	NO	YES	YES	YES	YES
2. Tuned to ZEUS $ep \rightarrow p+X$ data	NO	YES	YES	YES	YES
3. IntraNuclear Cascade	YES	NO	YES	YES	YES
4. Nuclear evaporation/breakup	YES	NO	YES	YES	YES
5. Multinucleon shadowing available.	YES	NO	NO	YES	YES
6. Correct nucleon remnant (n/p)	YES	NO	NO	YES	YES
7. Tuned to E665 $\mu Pb \rightarrow n+X$ data	YES	N/A	YES	YES/NO	YES
8. Shadowing coherence length	YES	N/A	NO	NO	YES

**But new issues discovered!**

# New issue for an eA collider!

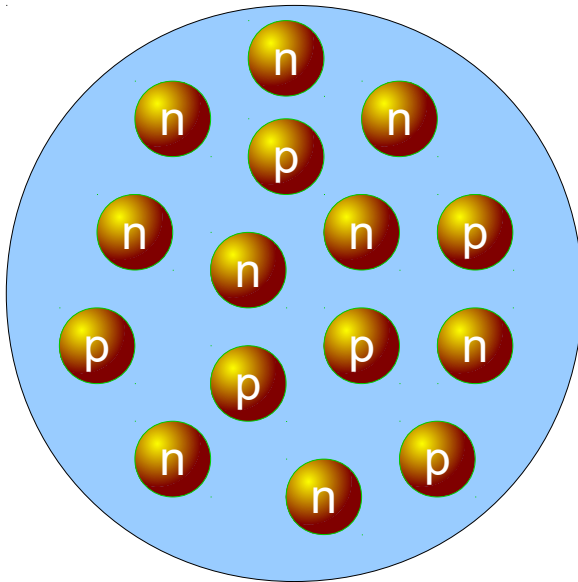
What is the momentum of the nucleon in a nucleus in the lab frame?

What is the mass of the proton inside the nucleus? Model dependent.

DPMJET & Pythia assume nucleons on-mass-shell.

## Target Rest Frame

$$M_{\text{Au}} = 197 \times 0.99983 \text{ amu}, \quad 1 \text{ amu} = 0.931494 \text{ GeV}$$



$$M_p = 1.0073 \text{ amu}$$



30-Nov-2016

$$M_n = 1.0087 \text{ amu}$$

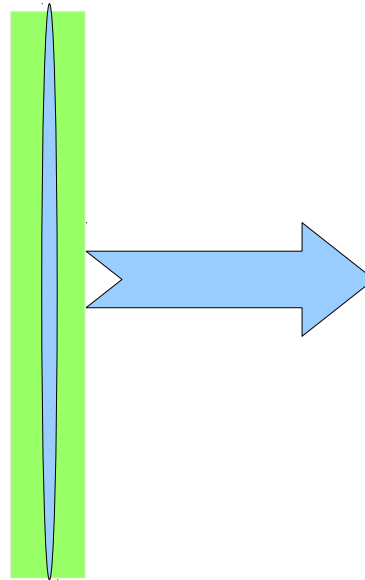


## Laboratory Frame

$$p_{z\text{Au}} = 197 \times 100 \text{ GeV/c}$$

$$\gamma\beta = p_z/M = 107.373$$

$$\gamma\beta \neq p_z/AM_p = 105.576$$



**NOT 100 GeV!**



$$p_z(p) = \gamma\beta M_p = 100.75 \text{ GeV/c}$$



$$p_z(n) = \gamma\beta M_n = 100.89 \text{ GeV/c}$$

More general physics question  
for BeAGLE (& EIC) to answer...

What is shadowing?

# What is "Shadowing"

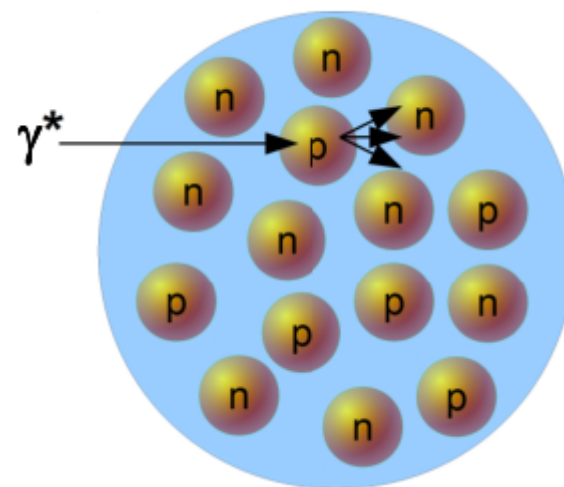
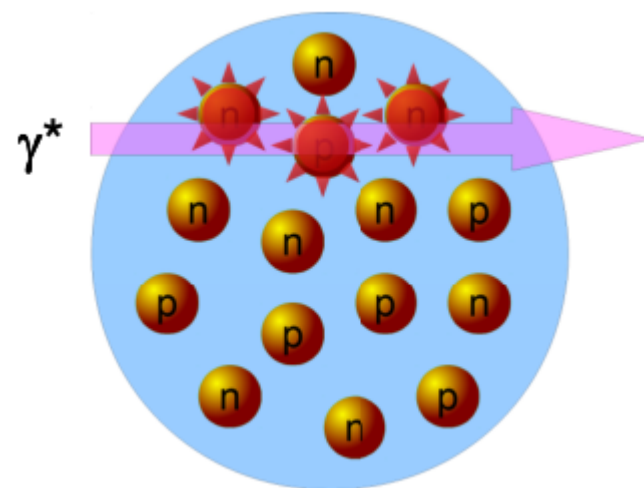
Shadowing can be defined as:

$$\sigma(eA) < A \sigma(ep)$$

It can, in principle be caused by literal shadowing, where the effect is dynamical and involves multiple nucleons...



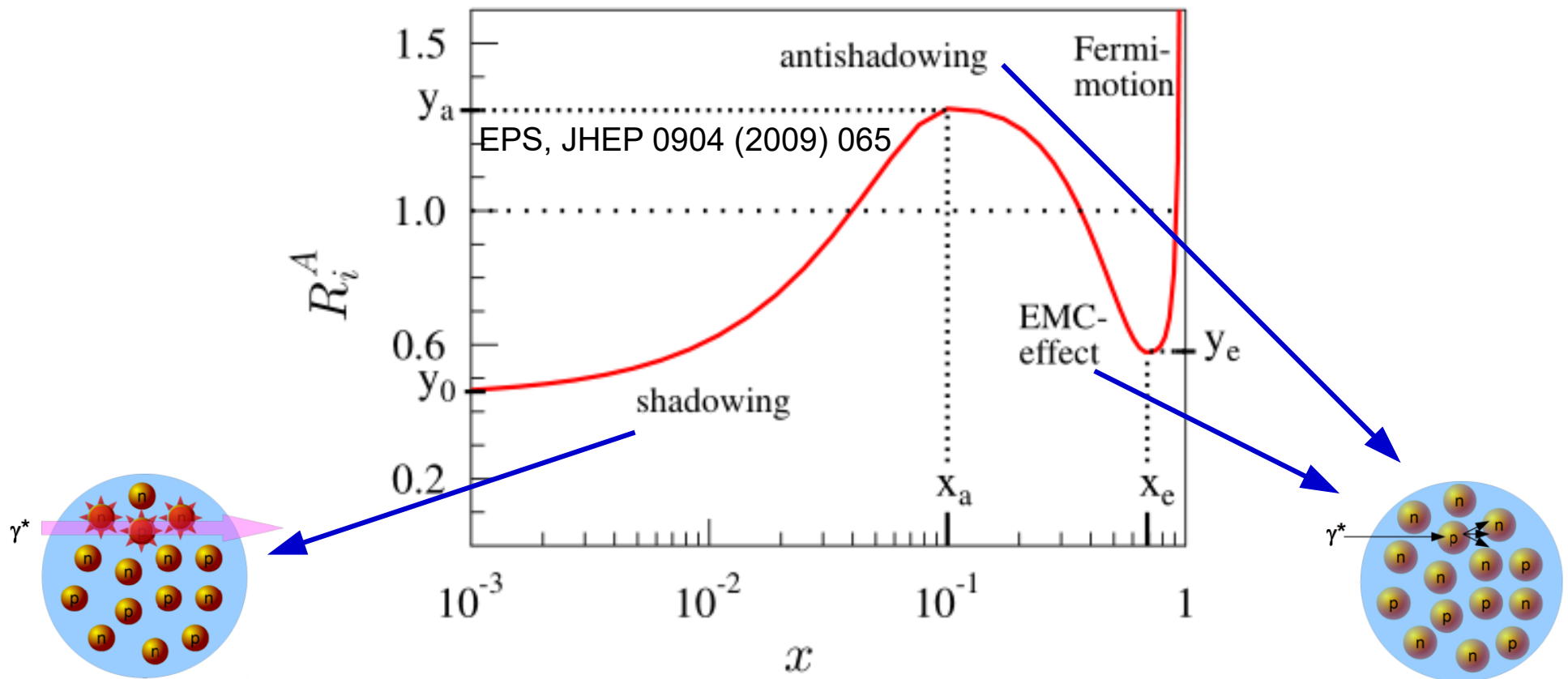
Or by modification of the individual nucleons on a slow timescale, followed by point-like interaction of the probe.



Or both??

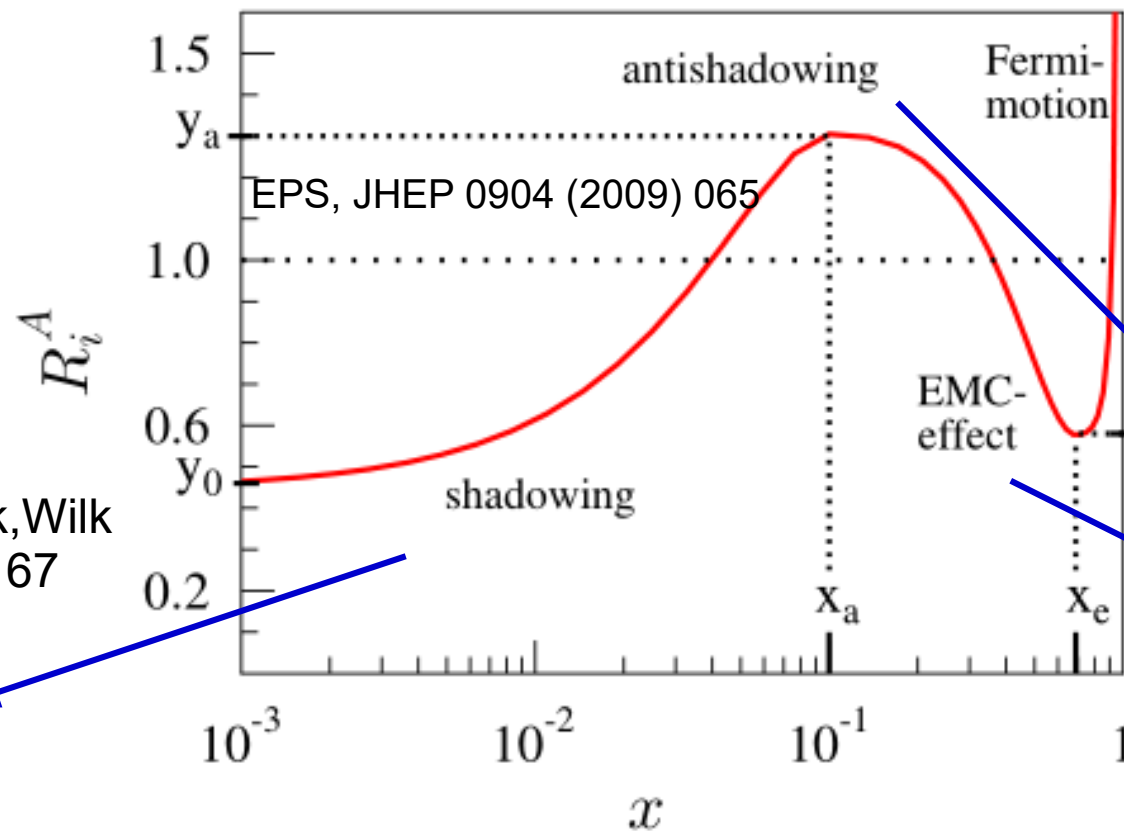
# BeAGLE shadowing approach genShd>1 (multinucleon at low x)

This is the basic conventional theoretical approach to low x eA,  
Details will vary by theorist...

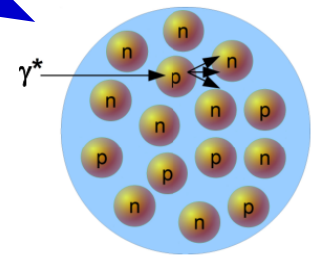
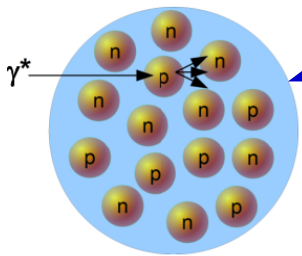


# DPMJetHybrid approach = BeAGLE: genShd=1

Alternate approach: Nucleons (or their pion cloud) change, but not the photon or the interaction. **Can we rule this out for low  $x$  eA?**



See e.g. Rożynek, Wilk  
PLB 473 (2000) 167

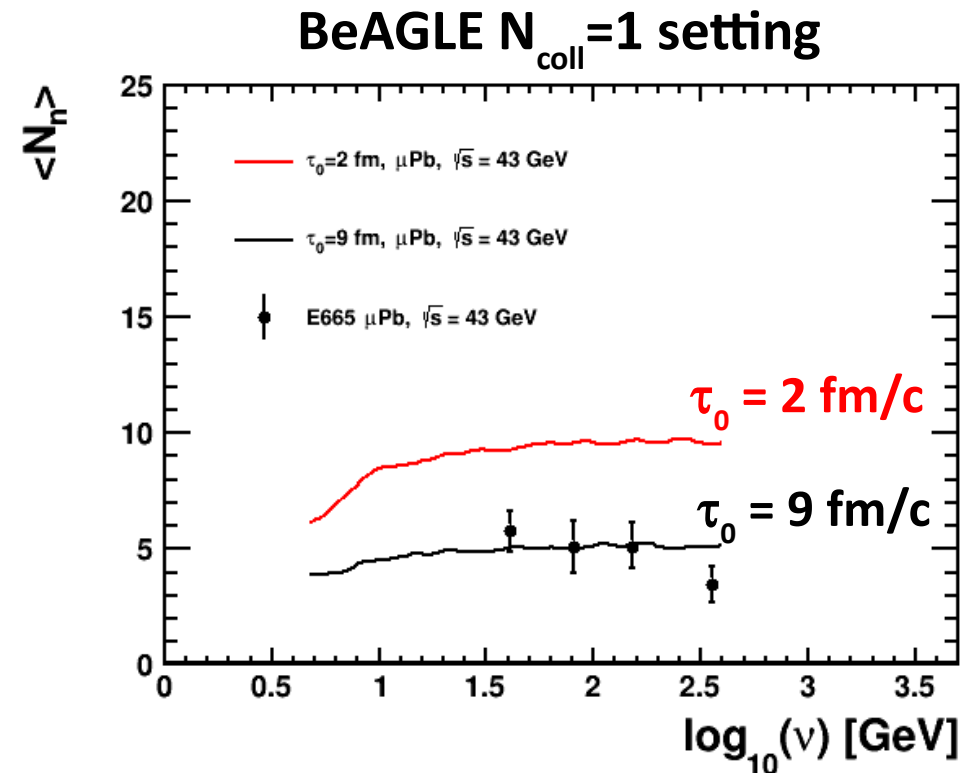
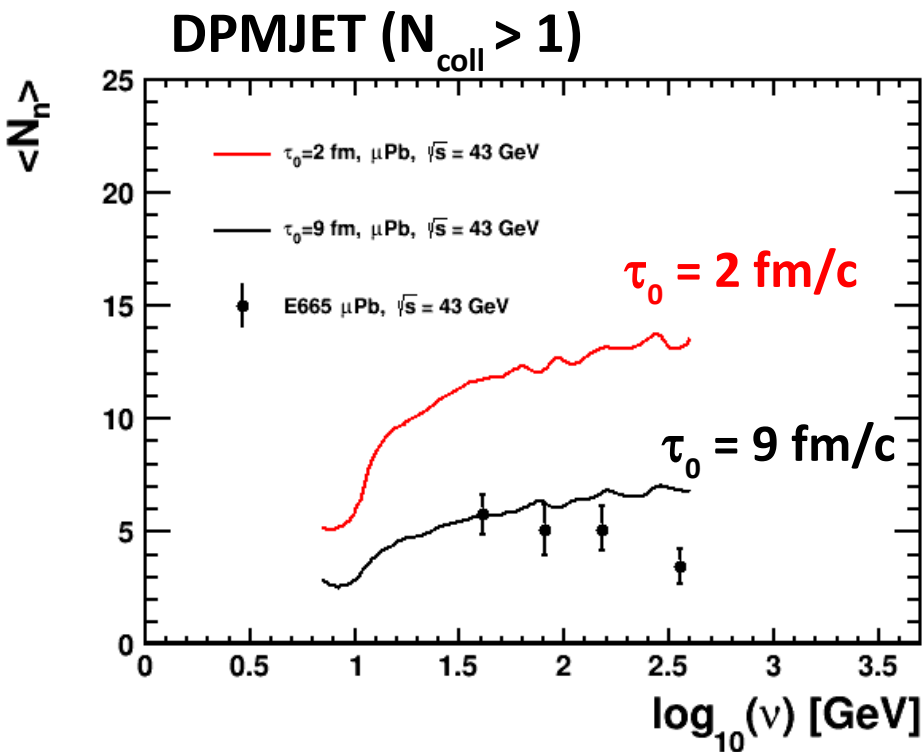


# E665 neutral data puzzle

E665, PRL 74 (1995) 5198

Evaporation neutrons ( $E-m < 10$  MeV)

Why so few evaporation neutrons even at high  $\nu$  (more shadowing)?



Zheng, Aschenauer, Lee,  
EPJA 50 (2014) 189

# E665 Streamer Chamber Puzzle

E665, ZPC 65 (1995) 225

Net charge  $\langle Q_T \rangle$  related to Total # of collisions, including INC

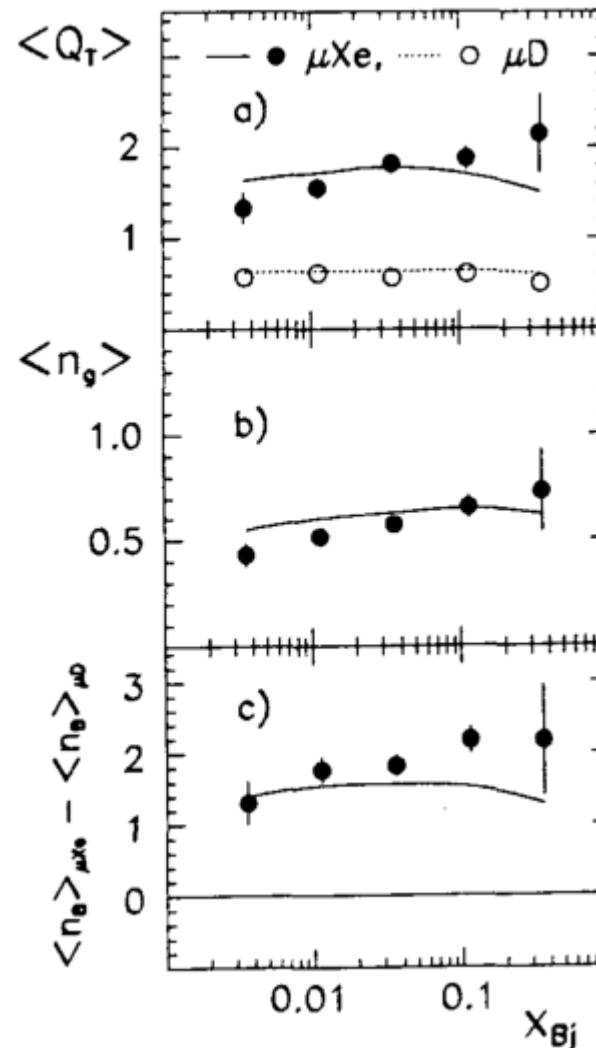
Why is it smaller at low  $x$  (shadowing region)?

# of grey tracks  $\langle n_g \rangle$  related to INC(IntraNuclear Cascade)

Why is it smaller at low  $x$  (shadowing region)?

# of black tracks  $\langle n_B \rangle$  related to INC + evaporation protons

Why is it smaller at low  $x$  (shadowing region)?



Validates and sharpens questions raised by neutrons!

# Diffraction fraction depends on A,x

E665, ZPC 65 (1995) 225

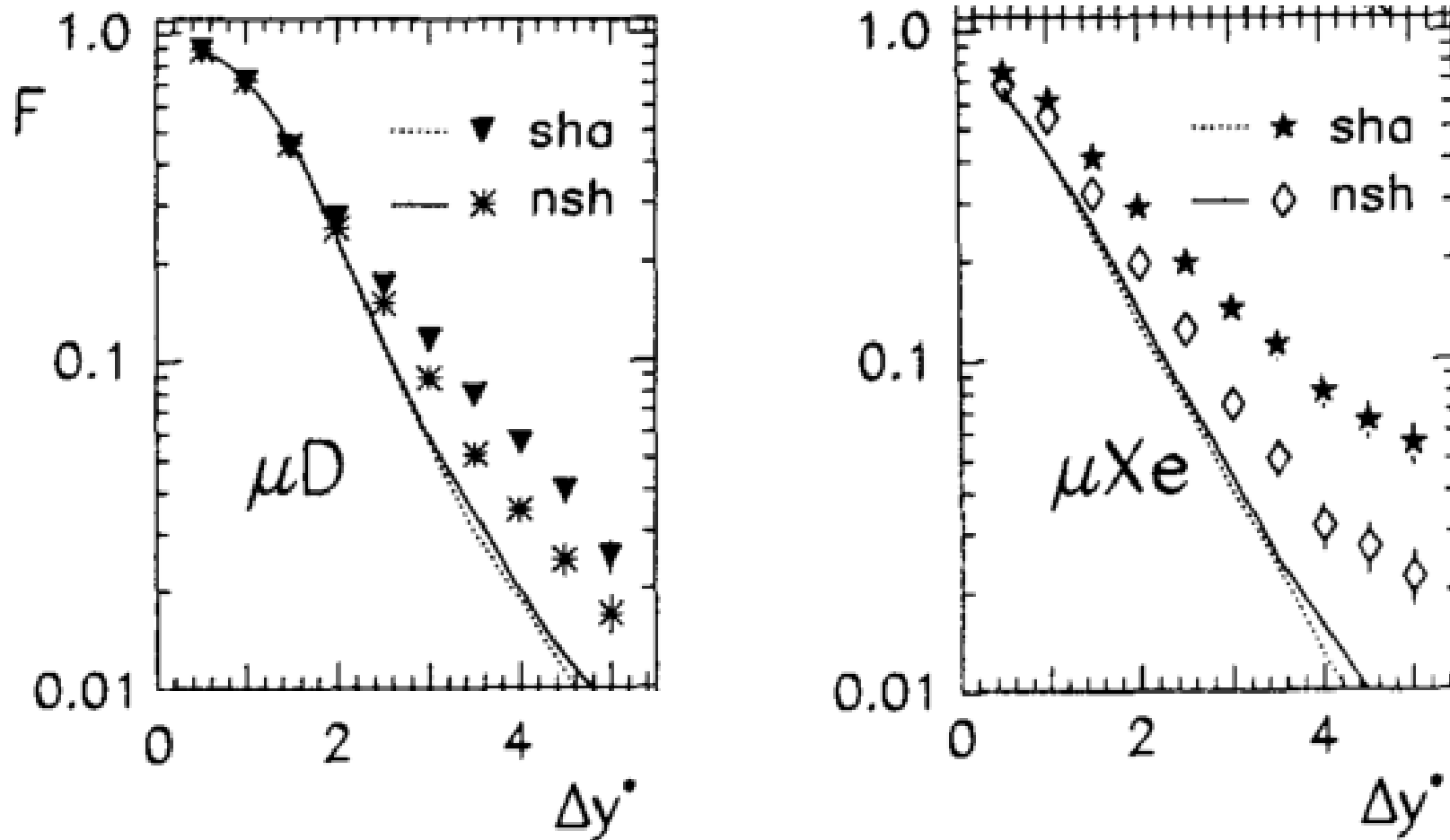


Fig. 20. Fraction of events with a rapidity gap greater than  $\Delta y^*$  as a function of  $\Delta y^*$ , in the shadowing and non-shadowing region, for  $\mu D$  and  $\mu Xe$  scattering. The lines represent the predictions of the VENUS model

# More general physics question for BeAGLE (& EIC) to answer...

What is shadowing?

BeAGLE needs:

- Process-specific  $A$ -dependence
- Intermediate options between  
mod. nucleons & dipole  $\sigma_{\gamma^*A}$

AND we need good EIC data!

# New issues...

Feature added or error corrected	DPMJet	Pythia (EIC)	DPMJet-Hybrid	BeAGLE $\beta$	BeAGLE (planned)
1. Correct eA target rest frame	NO	NO	NO	YES	YES
2. Partial shadowing effect	NO	NO	NO	NO	YES
3. Process-specific A dependence	NO	NO	NO	NO	YES
4. Tuned to more E665 $\mu$ A data	NO	N/A	NO	NO	YES
5. FS $p_F$ for hard process correct	???	NO	NO	NO	YES
6. Quenching correctly applied	N/A	N/A	NO	???	YES*
7. IS $p_F$ for hard process correct	???	NO	NO	NO	NO

\* - part of JLAB LDRD project

# JLAB LDRD



## FY17 Accepted Proposals

[Click here to submit a proposal](#)

[Download zip file](#)

Proposal #	Submitted By	Title	Date Submitted
2017-LDRD-2	Redacted		4/28/2016
2017-LDRD-3			4/28/2016
2017-LDRD-5			4/29/2016
2017-LDRD-6	Nadel-Turonski, Pawel	Geometry tagging for heavy ions at JLEIC	4/29/2016

# 2017-LDRD-6: Geometry tagging for heavy ions at JLEIC

Emphasis added for EIC R&D talk

A. Accardi, M. Baker, W. Brooks, R. Dupre, K. Hafidi, C. Hyde, V. Morozov (co-PI), P. Nadel-Turonski (PI), K. Park, T. Toll, L. Zheng.

# Anticipated outcomes/results

## Year 1 (FY17)

Emphasis added for EIC R&D talk

- Implement new model codes (**DPMJetHybrid**, **Sartre**) at JLab
- Interface to (GEMC) simulation of the full-acceptance detector
- Physics analysis of color propagation in eAu SIDIS in JLEIC kinematics
- First look at diffraction using **Sartre** (expanded to include Au, Pb, and Ca)
- Resolution for d and b in eAu for JLEIC using **DPMJetHybrid**

## Year 2 (FY18)

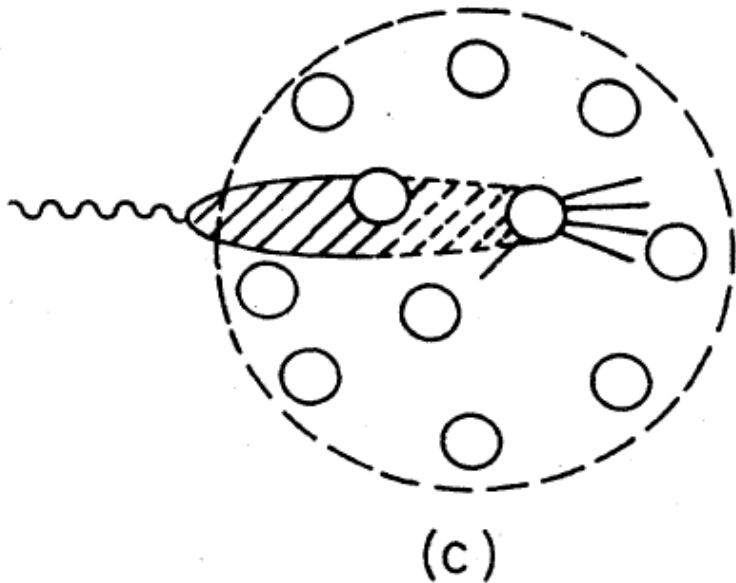
- Implement 3D Glauber in **DPMJetHybrid** for deformed nuclei (U)
- Use combination of **DPMJetHybrid** and Sartre for detailed studies of incoherent and coherent diffraction (ground state through photon detection)
- Expand color propagation analysis to include U and Ca
- Investigate tagging impact of including negative forward hadrons (pions)
- Fully clarify the physics impact of key JLEIC detector and IR features
- Implement **DPMJetHybrid** for JLab 12 GeV

# Summary

- **Multinucleon shadowing is in BeAGLE!**
  - Achieved main technical goal of eRD17
- Team is in place AT BNL!
- Plenty more to do.
- **Valuable tool for studying forward detector requirements**
  - To be used soon at both BNL & JLAB
  - Will achieve main strategic goal of eRD17

# Extras

# Basic idea of proposal



The virtual photon, in the target rest frame, can be treated as alternating between a point-like particle with  $\sigma \sim 0$  and a “dipole” or more complicated hadronic object with a larger  $\sigma$  (few mb). The coherence length of the “dipole” is  $\lambda \sim 1/(2Mx)$ . The fraction of the time it spends in this state is whatever fraction is needed for the total  $\sigma_{ep}$  to be correct.

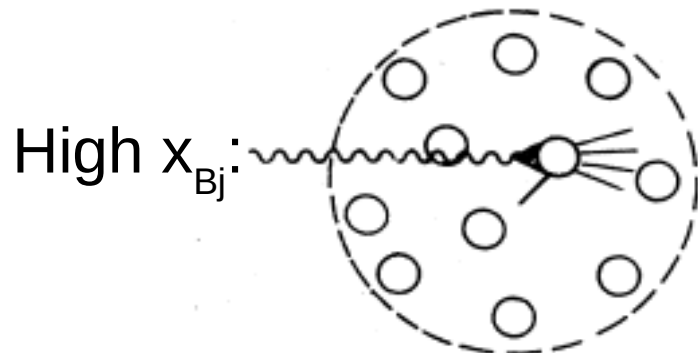
**Do NOT model saturation in detail to find  $\sigma_{\text{dipole}}(x, Q^2)$ !**

Rather, use an input value of nuclear shadowing  $R^{\text{Au}}(x, Q^2)$  to find  $\sigma_{\text{dipole}}(x, Q^2)$ . Then model probability of multiple nucleon DIS.

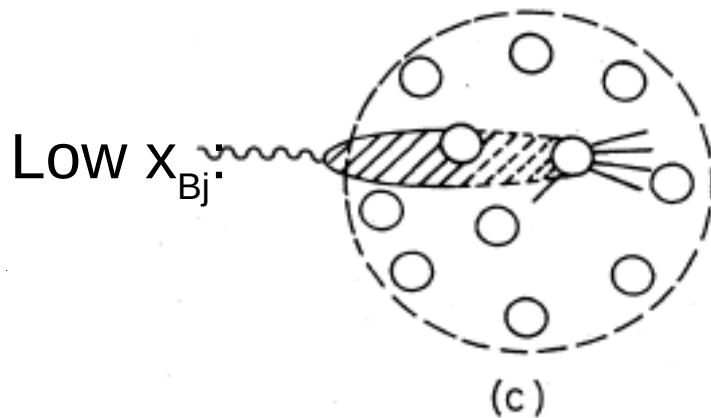
# eA: Basic Quantum Mechanics

$$\hbar=c=1 \quad r=0.88 \text{ fm} \quad 1/(2Mr) = 0.12 \quad \Delta p_z \Delta z = 1/2$$

Bauer, Spital, Yennie, Pipkin  
Rev. Mod. Phys. 50 (1978) 261



Nucleus Rest Frame (b)



(c)

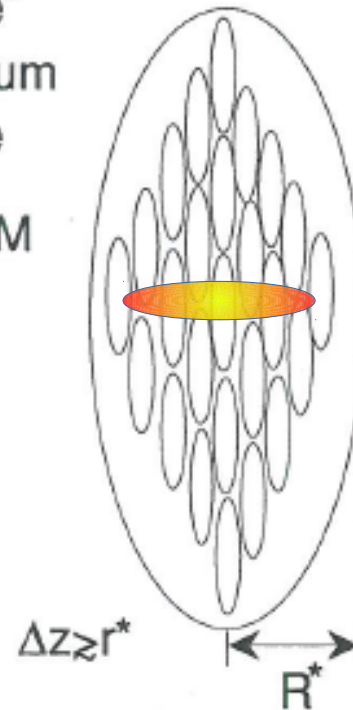
$$\lambda_h/r \approx 1/(2Mr) = 0.12/x_{Bj}$$

"Infinite"  
Momentum  
Frame

$$\gamma = P/M$$

$$r^* = r/\gamma$$

$$R^* = R/\gamma$$



$$p_z^{\text{quark}} = Mx\gamma$$

$$\Delta z = 1/(2Mx\gamma)$$

$$\Delta z/r^* = 1/(2Mr) = 0.12/x_{Bj}$$

**For  $x_{Bj} \ll 0.12$ , parton wavefunctions and/or interaction cannot be localized.**

# What if we do ep 10x100 anyway?

Recall:  $p_z = M_T \sinh y$

**Model independent boost:**

**Actual (Au) Target Rest Frame → Laboratory Frame**

$$M_{\text{Au}} = 197 \times 0.99983 \text{ amu}, \quad M_p = 1.0073 \text{ amu}, \quad M_n = 1.0087 \text{ amu}, \quad 1 \text{ amu} = 0.931494 \text{ GeV}$$

$$p_{z\text{Au}} = 197 \times 100 \text{ GeV}/c, \quad p_z/M = \gamma\beta = \mathbf{107.373}$$

$$\text{Since } p_T = 0: \sinh^{-1}(\gamma\beta) = \mathbf{y_{\text{boost}} = 5.3695}$$

**Naive boost:**

**Apparent p Target Rest Frame → Laboratory Frame**

$$p_{z(p)} = 100 \text{ GeV}/c, \quad p_z/M_p = \gamma\beta = \mathbf{106.579}$$

$$\text{Since } p_T = 0: \sinh^{-1}(\gamma\beta) = \mathbf{y_{\text{boost}} = 5.3620}$$

**Au in p-TRF:**

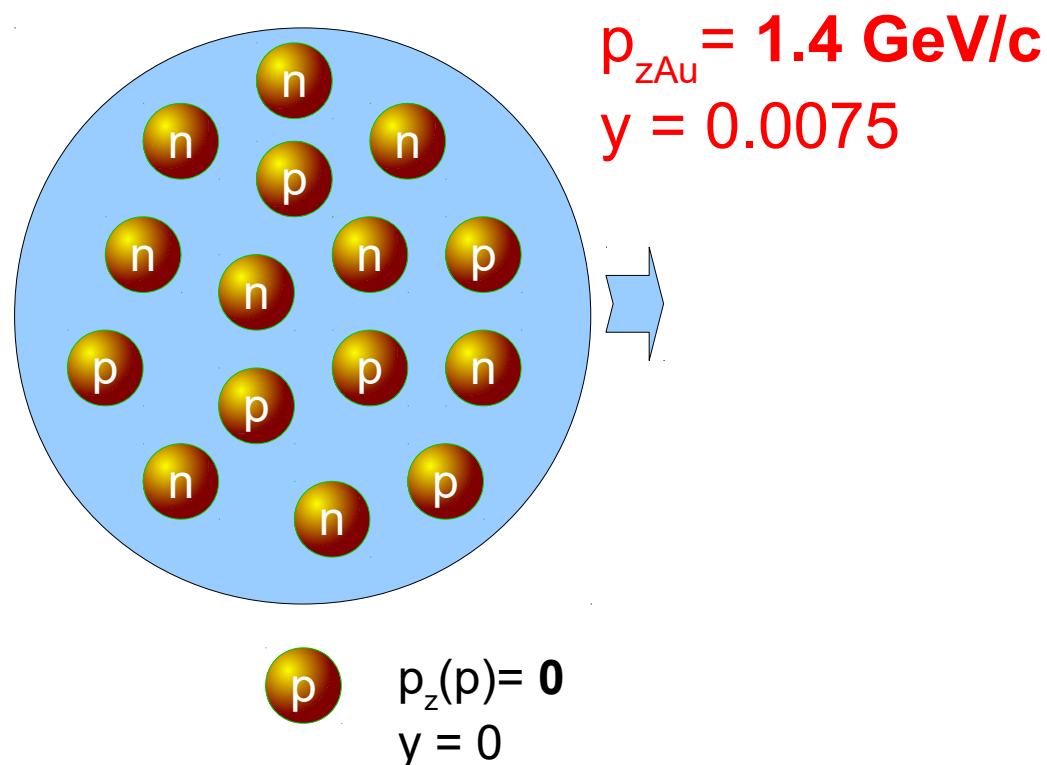
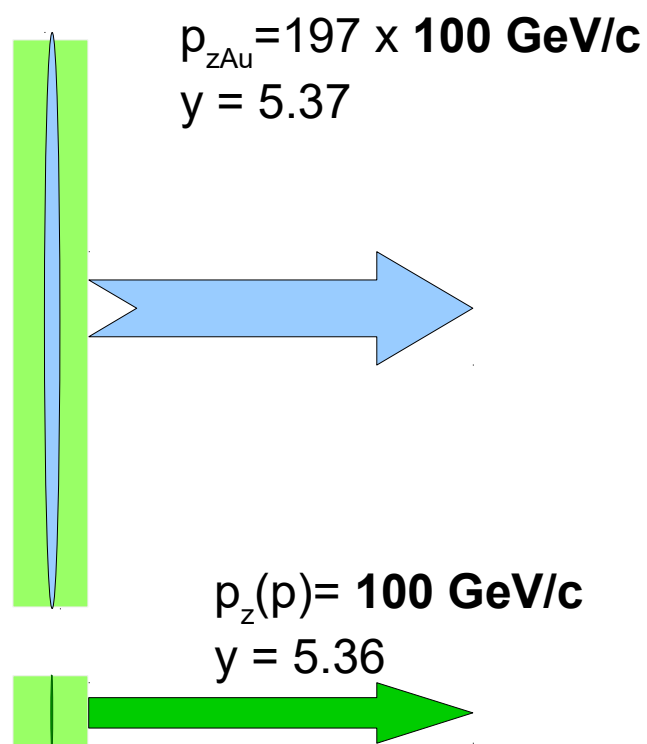
$$\text{Au nucleus: } y = 5.3695 - 5.3620 = \mathbf{0.0075}$$

$$\text{Since } p_T = 0: p_{z\text{Au}} = M_{\text{Au}} \sinh y = \mathbf{1.38 \text{ GeV}}$$

# What if we do ep 10x100 anyway?

**Laboratory Frame**

**Pythia p-TRF Frame**



**DPMJET & LHAPDF(!) count on nucleus at rest in TRF.**

# Tune (or debug) BeAGLE

First try with BeAGLE led to WAY  
too much excitation energy for  $N_{part} > 1$ .  
**Needs to be fixed before we do physics...**

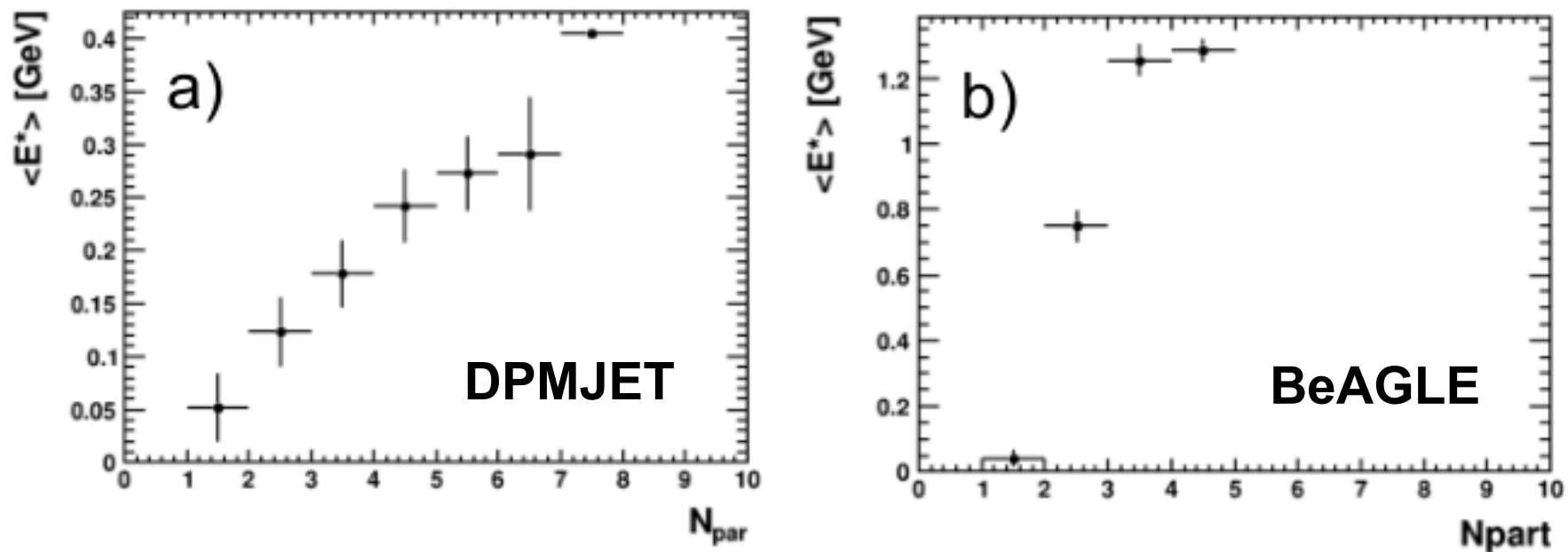
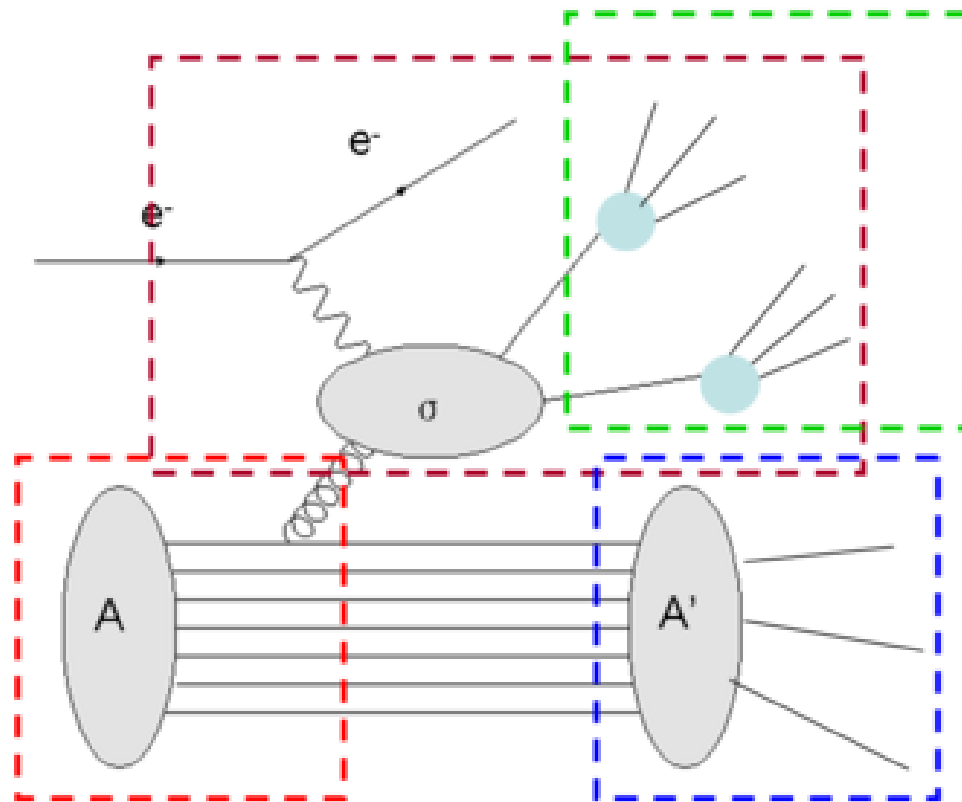


Figure 2. Average nuclear excitation energy of the nuclear remnant in a **Fixed Target ePb** collision as a function of the number of participating nucleons for a) DPMJet and b) BeAGLE.

# DPMJet-Hybrid Structure

From: <https://wiki.bnl.gov/eic/index.php/DpmjetHybrid>



A hybrid model consisting of DPMJet and PYTHIA with nPDF EPS09.

Nuclear geometry by DPMJet and nPDF provided by EPS09.

Parton level interaction and jet fragmentation completed in PYTHIA.

Nuclear evaporation ( gamma dexcitation/nuclear fission/fermi break up ) treated by DPMJet

Energy loss effect from routine by Accardi, Dupré Salgado&Wiedemann to simulate the nuclear fragmentation effect in cold nuclear matter

# Geometry tagging physics

## Chapter 3: The Nucleus: A Laboratory for QCD (p59)

Can the nucleus, serving as a color filter, provide novel insight into the propagation, attenuation and hadronization of colored quarks and gluons?

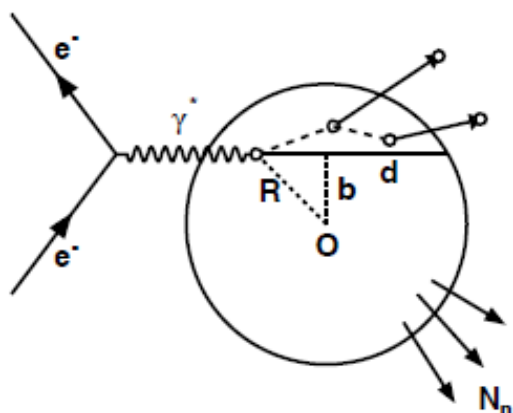
using the nucleus as a space-time analyzer the EIC will shed light on answers to the questions such as the following: How does the nucleus respond to the propagation of a color charge through it? What are the fluctuations in the spatial distributions of quarks and gluons inside the nucleus? What governs the transition from quarks and gluons to hadrons?

Geometry tagging is essential for this goal!

What is the role of saturated strong gluon fields, and what are the degrees of freedom in this high gluon density regime? An EIC will allow us to probe the wave functions of high-energy nuclei. By studying these interactions, one may probe the strong gluon fields of the CGC, possibly the strongest fields in nature. In ...

Geometry tagging is required to address this goal with 40 GeV\*A ion energies. Further enhances saturation at 100 GeV\*A ion energies.

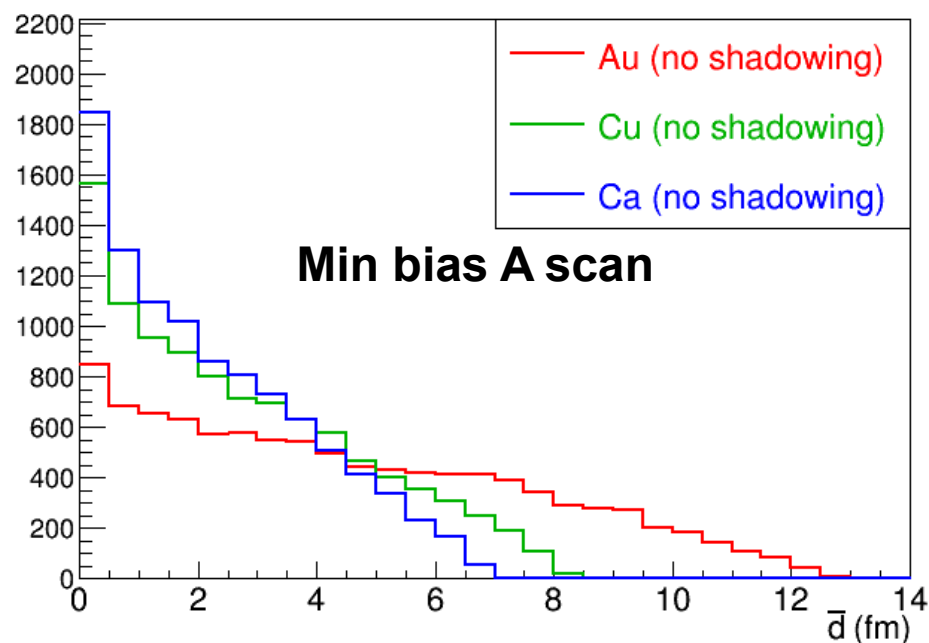
# Geometry tagging (w/o shadowing)



Intra-nuclear cascading increases with  $d$  (forward particle production)

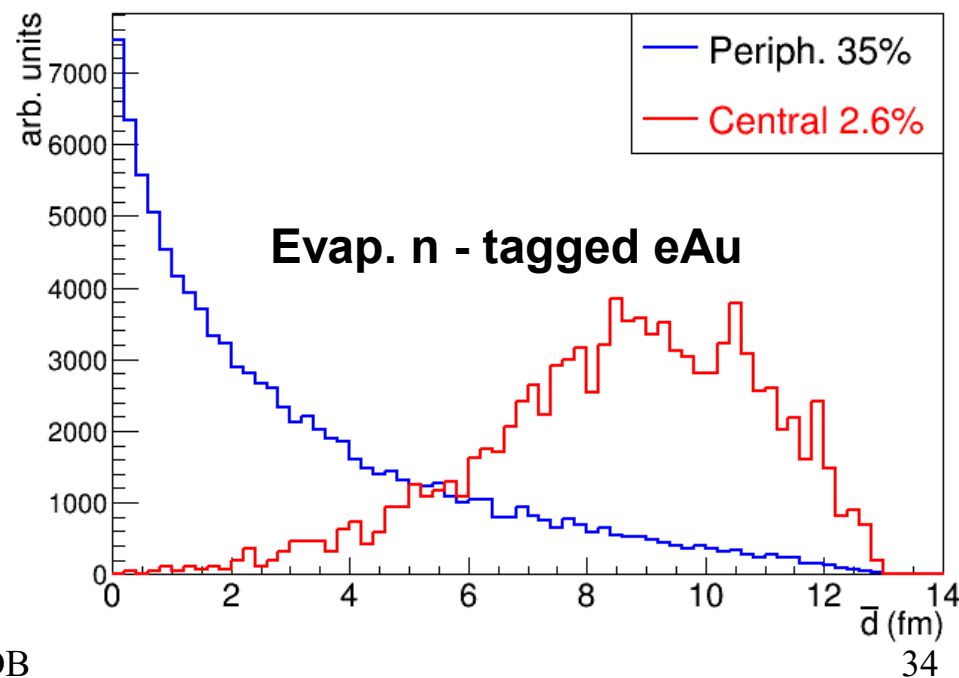
Leads to more evaporation of nucleons from excited nucleus (very forward)

**LOOKS GOOD!**



27-Jan-2017

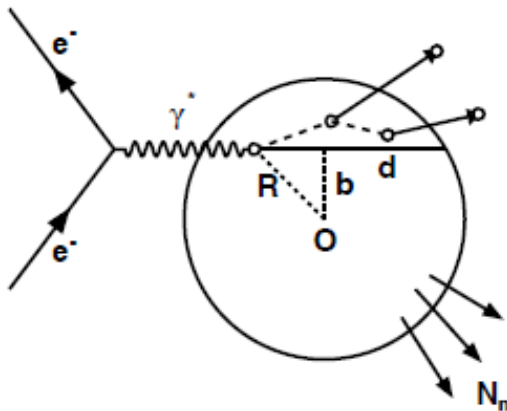
Tagged eAu (samples scaled to same area)



MDB

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# Geometry tagging b vs. d



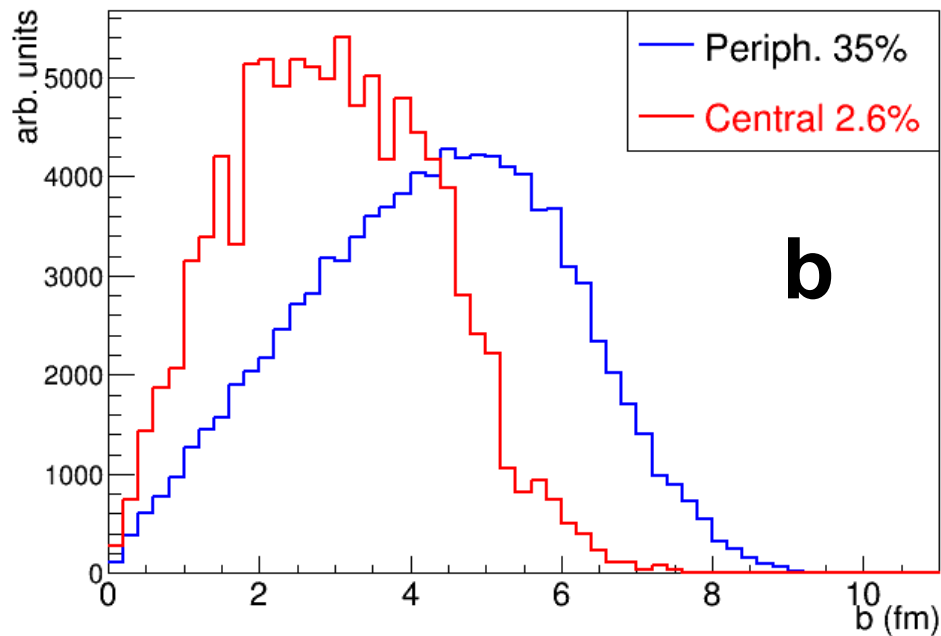
Intra-nuclear cascading increases with  $d$  (forward particle production)

Leads to more evaporation of nucleons from excited nucleus (very forward)

**Evap. n - tagged eAu**  
**No shadowing**

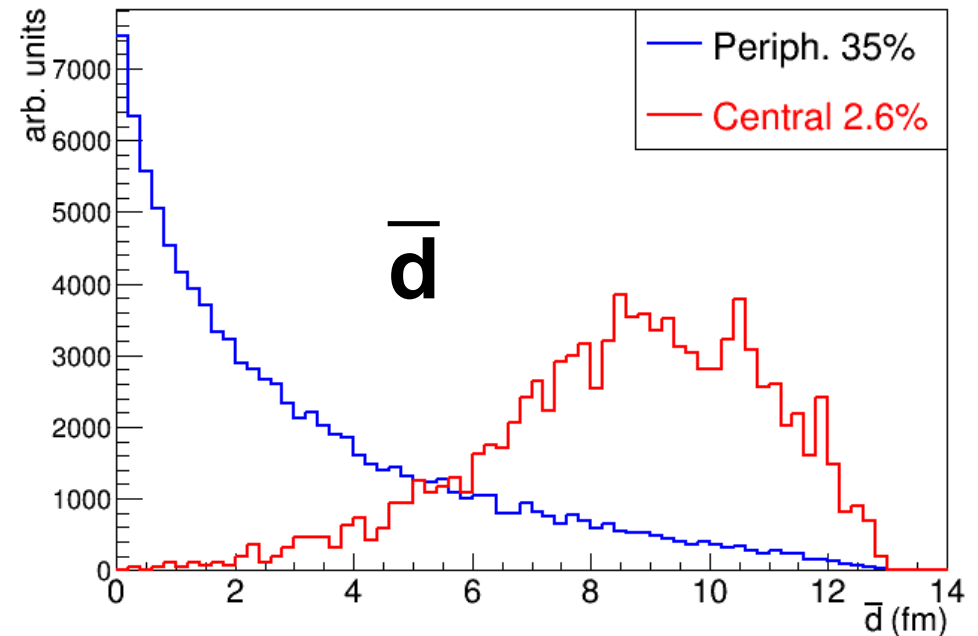
**$b$  is indirectly taggable**  
**because it correlates with  $d$ .**

Tagged eAu (samples scaled to same area)



27-Jan-2017

Tagged eAu (samples scaled to same area)



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# E665 & Neutron Detection

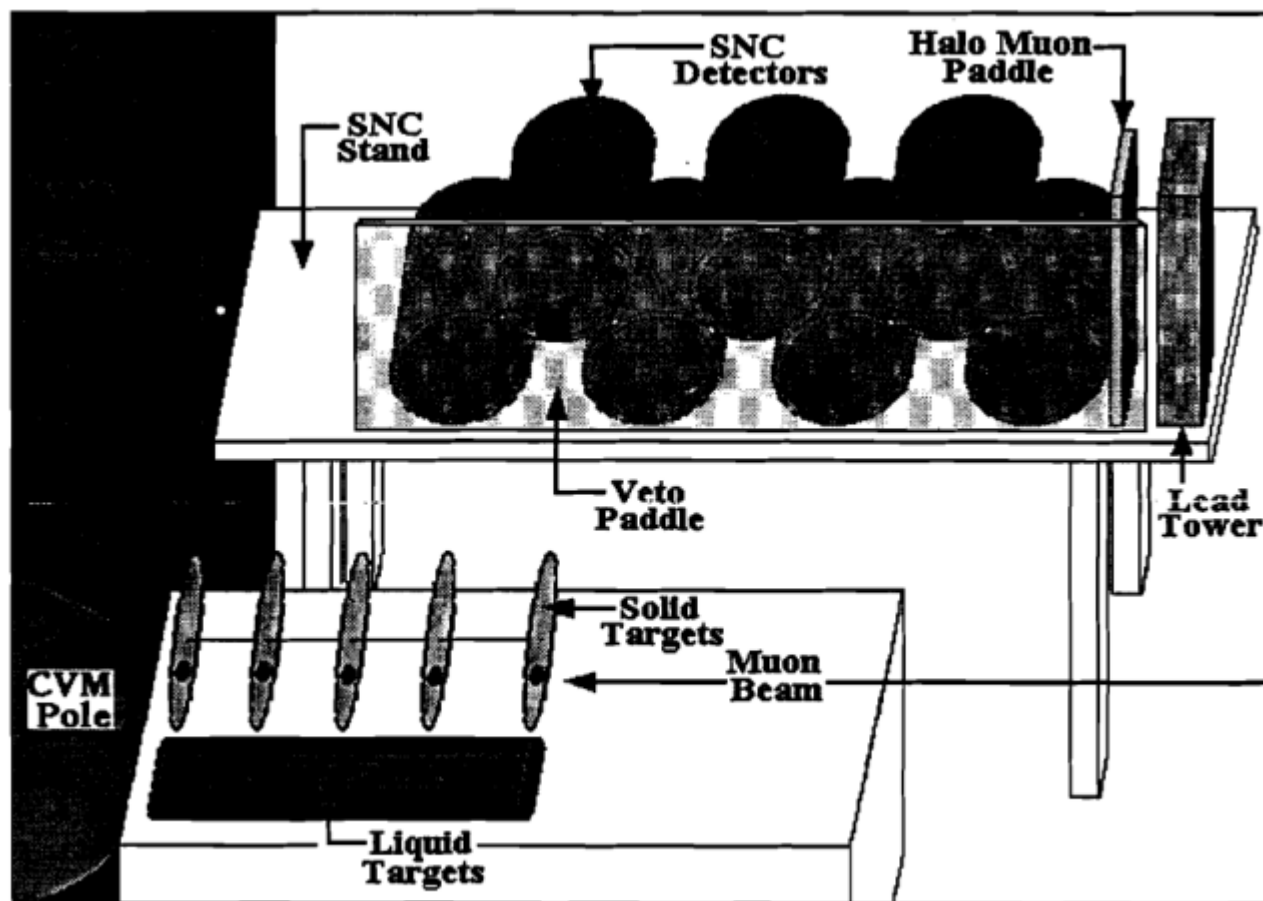


Figure 5.1: Location of the SNC experimental setup with respect to the target-vertex area.

PhD Thesis, Henry Clark, Ohio University (1993)